# Valve Preamplifier (I)

## Based on the ECL86

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The good old valve amplifier is experiencing a renaissance. Consequently, we present a valve preamplifier that unquestionably belongs to the high end.

In the high-end region, valve amplifiers enjoy uninterrupted popularity. Although a lot of things can be done with modern semiconductors, the old-fashioned valve is still very much in the news in elevated audio circles. In both domestic and studio equipment, valves are being used increasingly often in equipment such as compressors, equalisers, simple amplifiers, filters and the like. The objective is to achieve a warmer, more attractive sound than what can be obtained using only sterile semiconductor technology. The digital era in particular gives many recordings an unpleasant sharpness, which can be moderated by the knowledgeable and consistent use of valve technology. The valve preamplifier described here usually makes CDs sound more pleasant than they other-

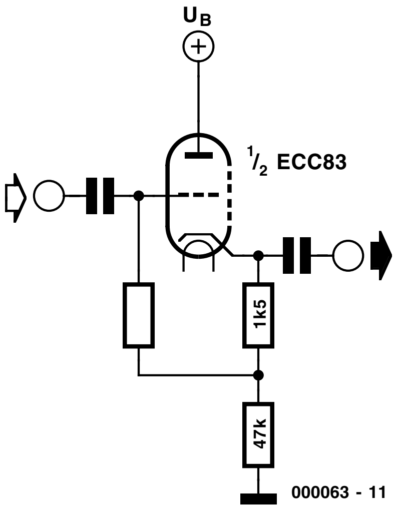

Figure 1. A standard valve preamplifier configuration using one ECC83 for the two channels.

wise would.

This preamplifier is a no-compromise design. Only valves are used in the signal path, while semiconductors are used for the auxiliary functions. In this way, the two technologies complement each other. To be consistent, we have also avoided using semiconductors for switching in the signal path.

## The valve determines the design

The choice of the amplification elements, the valves, largely determines the topology of the circuit. Given the limited selection of suitable valves, a few basic designs have come to predominate. However, these all have certain significant disadvantages.

A typical preamplifier, for example, is fitted with ECC81, ECC82, ECC83, ECC88 or similar valves. The ECC83 has a high no-load gain, but only a small working current (1 to 1.5 mA). The ECC81 and ECC82 have lower gain, but they can be operated at currents up to 10 mA. The ECC88 (or the equivalent type PCC88) is most commonly used in television sets, but it is also popular for low-frequency applications, since it can work at currents of up to 15 mA, with an operating voltage of only 90 V.

Connecting two double triodes in series, however, provides far more gain than is needed nowadays, while still not providing an adequate amount of current. In order to reduce the output resistance, a cathode follower circuit is frequently used. This significantly diminishes the dynamic output resistance, although it does not completely eliminate it. A typical cathode follower circuit using an ECC83 is shown in **Figure 1**. The dynamic output resistance $R_d$ is given by the formula:

$$R_d = \frac{R_i \cdot R_k}{R_i + R_k \cdot (\mu + 1)}$$

With the following typical values for the ECC83, this yields the following value for $R_d$:

no-load gain: $\mu = 100$
internal resistance: $R_i = 62.5\ \text{k}\Omega$
anode current: $I_a = 1\ \text{mA}$
cathode resistance: $R_k = (47 + 1.5)\ \text{k}\Omega$

$$R_d = \frac{64.5 \cdot 48.5}{62.5 + 48.5 \cdot (100 + 1)}$$

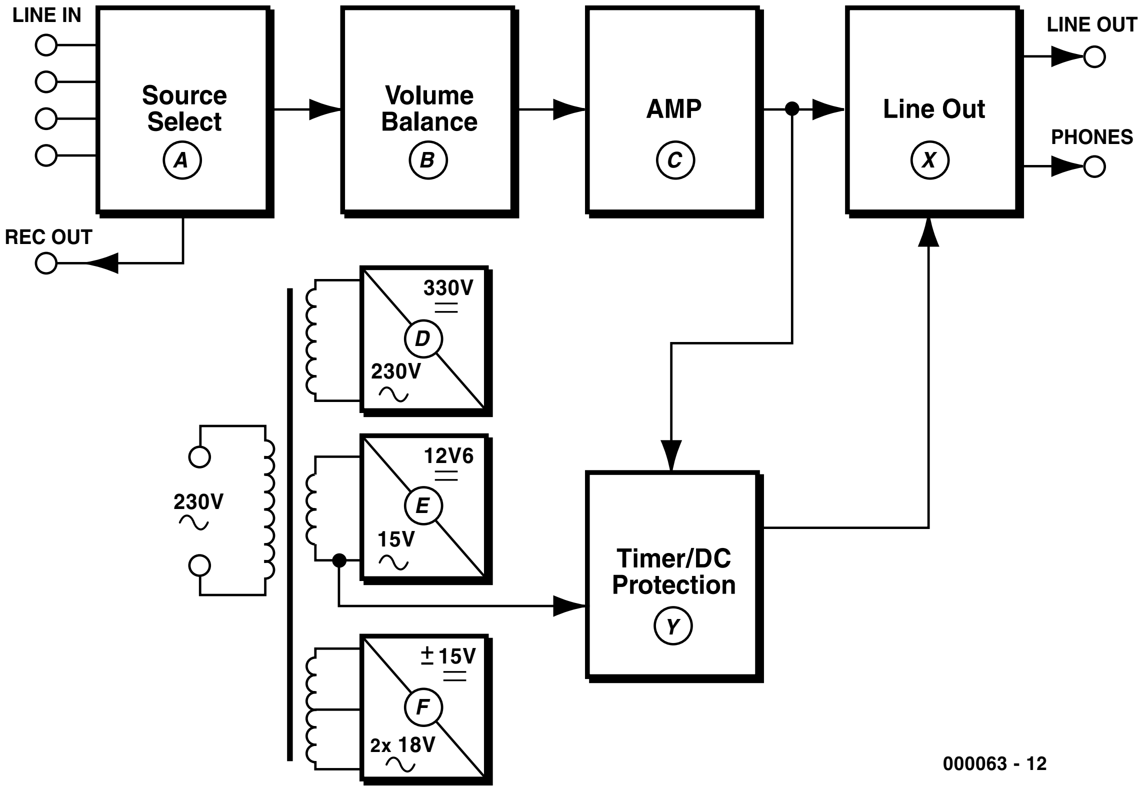

Figure 2. Block diagram of the preamplifier, showing its modular design.

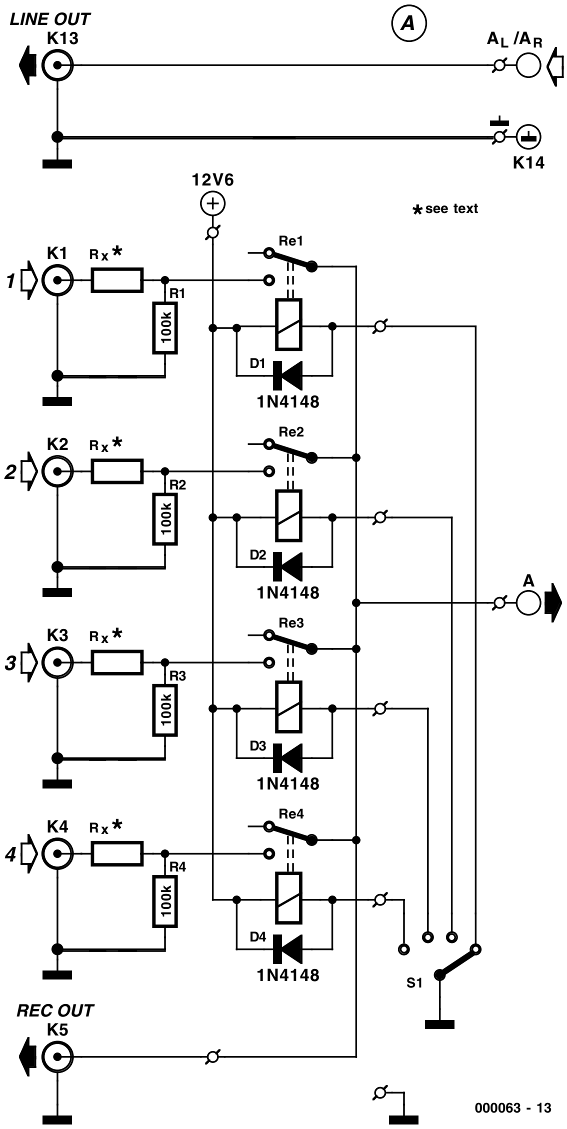

Figure 3. The external connections: the schematic diagram of the relay board with the inputs and outputs.

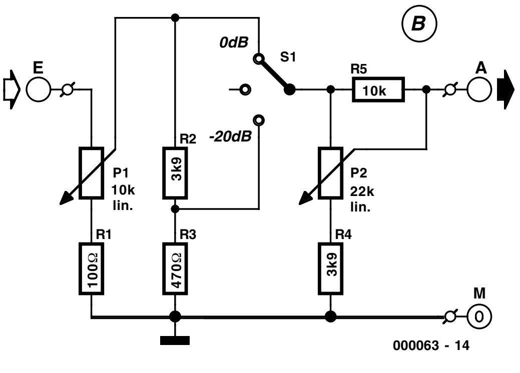

Figure 4. Here is where the volume and balance are adjusted.

This appears to yield a low output impedance. However, in actual fact the total cathode resistance (48.5 kΩ) or the internal resistance of the valve will determine the effective output resistance of this arrangement (strictly speaking, only if it is overdriven). If we assume that the net capacitance of the circuit and the output cable is only 500 pF, which is easily possible with cables that are a few metres long, the attenuation at 20 kHz is 14 dB. This is why you often see recommendations to limit the cable length to 1.5 metres and to use the lowest-capacitance cable that is available. This certainly helps to reduce the problem, but it does not eliminate its source. The sound of the system will be audibly different when different types of cable are used, and this is a natural consequence of the construction of the amplifier.

Using a single valve for both stereo channels is a mistake that has been inherited from the early days of stereo hi-fi technology, and which has proven to be almost impossible to eradicate. The channel separation suffers, due to capacitive crosstalk within the valve and in wiring of the valve socket, and this considerably impairs the spaciousness and detail resolution of the sound.

Valve amplifiers are often operated without negative feedback. This may not have caused any problems in the days of monophonic sound, but the only way to guarantee proper stereo reproduction is to use strong feedback to achieve equal performance in the two channels of a stereo system, regardless of tolerance variations in the characteristics of the valves. This also causes the distortion factor to remain very low, even when the amplifier is driven hard, and it flattens the frequency response. This also satisfies the demand for the lowest possible distortion in the preamplifier.

For all of these reasons, the preamplifier described here does not follow the conventional path. An ideal amplifier has a high input impedance, a high no-load gain and a low output impedance. These conditions are easily satisfied by operational amplifiers using semiconductor technology. With valves, the situation is far more difficult. In order to avoid the above-mentioned design shortcomings, an ECL86 double valve is used here. The triode section of this valve is exactly the same as that of an ECC83. The pentode section can be used as a power amplifier that can deliver 4 watts with an anode current of 36 mA and a distortion factor of 10 percent. If we properly combine the triode and pentode sections, we can obtain a sort of valve operational amplifier with good characteristics that are similar to those of a modern semiconductor opamp.

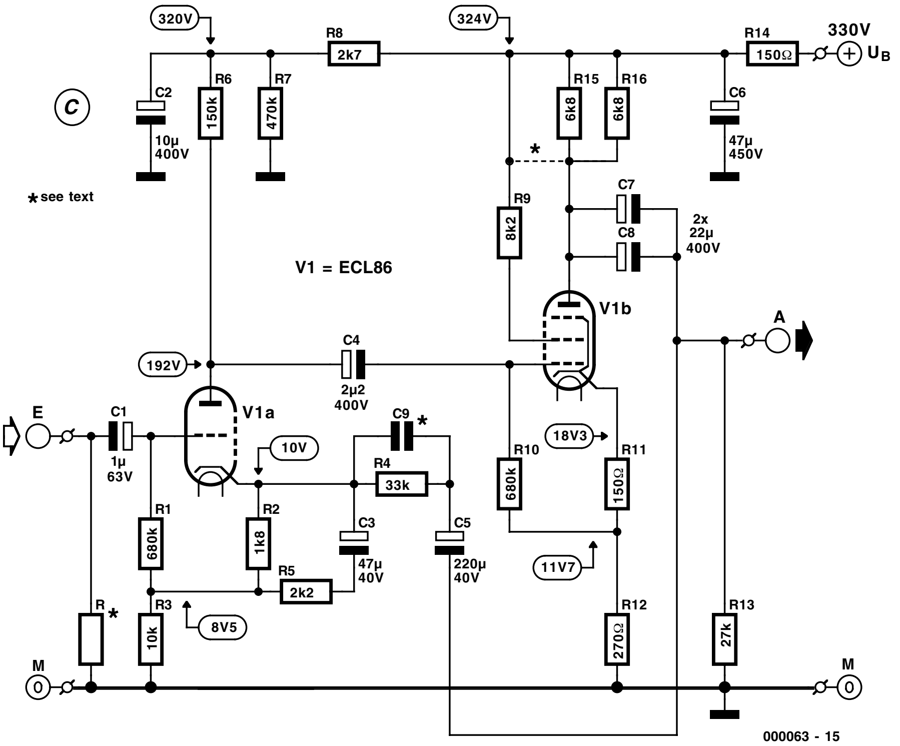

Figure 5. The highlight of the design is the valve amplifier stage.

## Modular design

The block diagram of one channel of the preamplifier is shown in **Figure 2**. A modular approach is used in the design, with each functional group located on a separate printed circuit board. The amplification chain consists of four elements, which are the input selector circuit, the volume/balance adjustments, the actual preamplifier and a changeover switch for line or headphone outputs. A protective circuit with a time delay switches the outputs to earth when a fault is detected in the output signal. An external power supply is used. The modular construction not only allows the circuit to be modified relatively easily, it also promises very good values for channel separation and the signal-to-noise ratio. This makes up for the increased cost and effort for the wiring.

In the following descriptions of the individual modules, the component numbers correspond to the labels on the circuit boards. In contrast to the usual practice with Elektor projects, the components are not numbered sequentially for the complete circuit, but instead separately for each module. Only one channel of the amplification chain is shown; the component numbers for the second channel are either shown in parentheses or are distinguished by a 'prime' mark ( ' ).

## Input selection with relays

The input selection module shown in **Figure 3** is laid out for four signal sources K1 through K4 (K6 through K9) that are connected to a single common line via the single-in-line reed relays Re1 through Re4 (Re5 through Re8). The consistent use of screening and the split layout of the printed circuit board provide a high degree of channel separation from the very start.

The 100-kΩ resistors R1 through R4 (R5 through R8) terminate the input sockets and conduct any static charges to earth. They prevent clicks when a different input source is selected or the input cables are reconnected. The resistors labelled Rx can be used with signal sources that have different output levels; their values can be chosen as necessary. However, you should make sure that the series resistance for K5 (K7) matches the source resistance for the tape recorder output. If the resistance is too large, high tones will be lost.

The 12-V relays, which are powered by the +12.6-V DC filament supply voltage, are switched by the

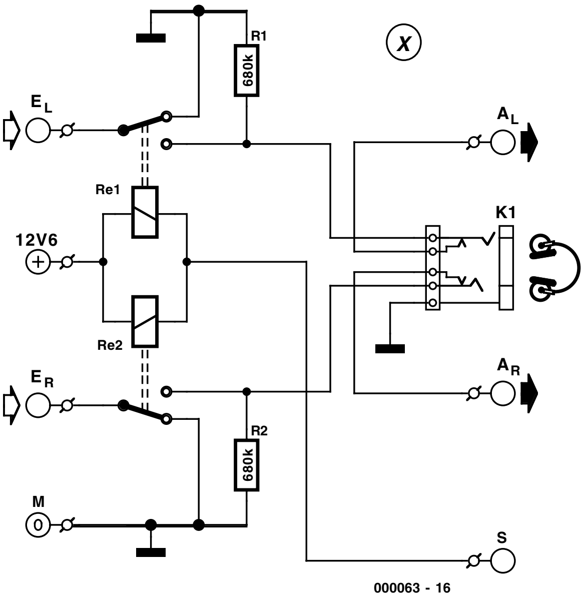

Figure 6. The headphone and line output connections.

rotary switch S1. This is connected to the circuit board via solder posts.

The line out sockets K13 (K15) and the earth terminals K14 (K16) are located on the same circuit board, but they are fully electrically isolated from the rest of the board. The tape recorder output sockets must be mounted externally, and then connected to solder posts K5 and K7 (earth to K17).

## Volume adjustment

From connector K5 (K7) of the relay board, the signal is conducted to the circuit shown in **Figure 4** for adjusting the volume, balance and muting. The potentiometers that are used, with 41 detent positions, have good reproducibility. The balance adjustment also has a fixed midpoint setting. The mute switch S1 spreads the adjustment range, so that even low volume levels can be sensitively adjusted. If you find the 20 dB step unsuitable, you can modify the values of the resistors. The sum of R2 (3.9 kΩ) and Re (470 Ω) should remain approximately the same, but the individual values can be modified as desired. When the mute switch is in the middle position, the signal path is interrupted, and the output is muted.

The characteristic curve of the linear volume adjustment potentiometer P1 (which has good tracking due to its linearity) is slightly modified by inserting R1 between its lower terminal and earth. This compensates for the slight imbalance between the two channels in the initial region of the volume adjustment, which arises from the construction of the preamplifier. Of course, with such an arrangement it is not possible to set the volume level fully to zero.

The balance control P2, in combination with R4 and R5, has an adjustment range from around +3 dB to –4 dB. This is fully adequate for correcting the midpoint. With the indicated component values and the 100-kΩ resistors on the relay board, at the middle position of the balance control the input resistance is approximately 2.2 kΩ. This is a suitable value for all modern signal sources, and it is low enough to keep the disturbance sensitivity and the total noise at low levels.

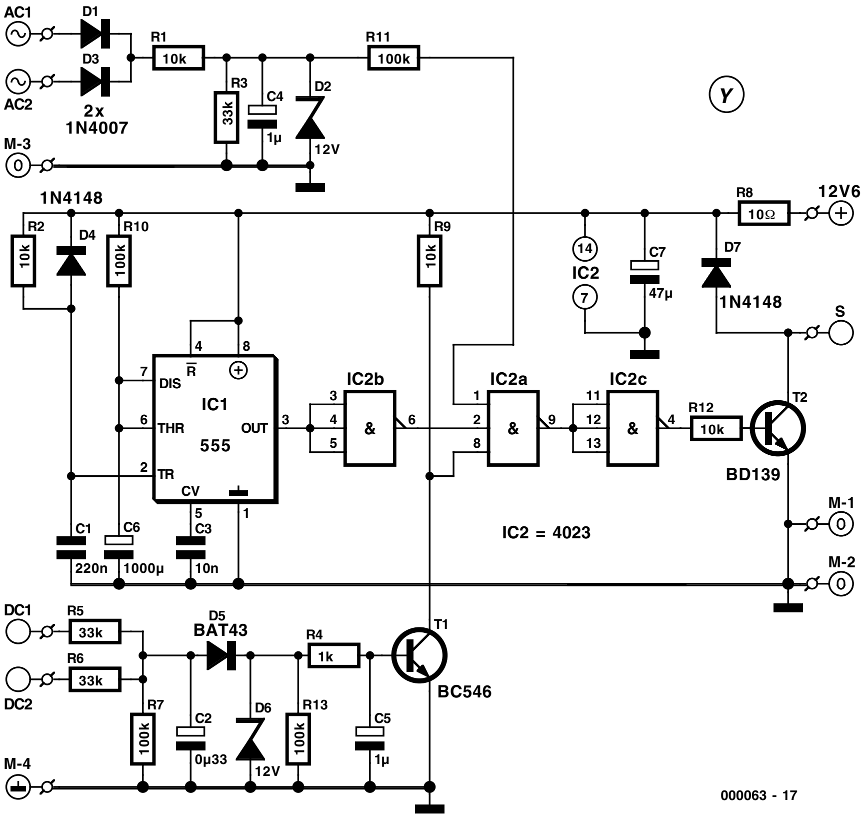

Figure 7. The protective circuitry monitors the state of the preamplifier and switches the output relays.

## The amplifier

The amplifier module shown in **Figure 5** makes a familiar impression. Valve V1a is the triode section of the ECL86, equivalent to half of an ECC83. The DC operating point is set to just below 1 mA by R2. The amplified signal reaches the pentode section V1b via capacitor C4. Neither section of the valve is wired in the conventional manner. The cathode and the grid bleeder resistor are not connected directly to earth, as is usual, but instead via resistors R12 and R3, respectively. This provides local negative feedback for each valve section. This constrains the valves to work at well-defined operating points, so it is not necessary to use selected valves.

The load resistance of V1b consists of R15 and R16 in parallel (each 6.8 kΩ, 4.5 W). This divides the not insignificant power dissipation equally over two component packages. The signal is coupled out via two parallel 22-$\mu$F capacitors (C7 and C8). Using two capacitors instead of a single 47-$\mu$F capacitor halves the ESR (effective series-resonant resistance) of the output capacitor, which benefits the high frequency transfer characteristic of the amplifier. Resistor R13 bleeds off static charges.

To ensure that the circuit has a well-defined behaviour, the output signal is coupled back via C5 and R4 in negative feedback. The basic amplification of V1a depends on the load resistance of R6, the operating voltage (the voltage across C2) and the cathode circuitry. Resistors R2 and R5 are connected in parallel for AC signals. The amplification is thus determined by the relationship of the parallel combination of R2 and R5 to the resistance of R4. If you want to modify the basic amplification, you can change the values of R5 or R4. The smaller the resistance of R4, or the larger the resistance of R5, the higher the gain. Capacitor C5 separates the AC and DC currents, so that the DC operating point of V1a does not shift. Resistor R2 may not be modified to change the gain, since this would shift the DC operating point in an unacceptable manner.

The supply voltage, $U_B$, is 330 V. It is decoupled and filtered by R14 and C6, in order to avoid channel crosstalk via the supply voltage. The supply voltage is further decou-

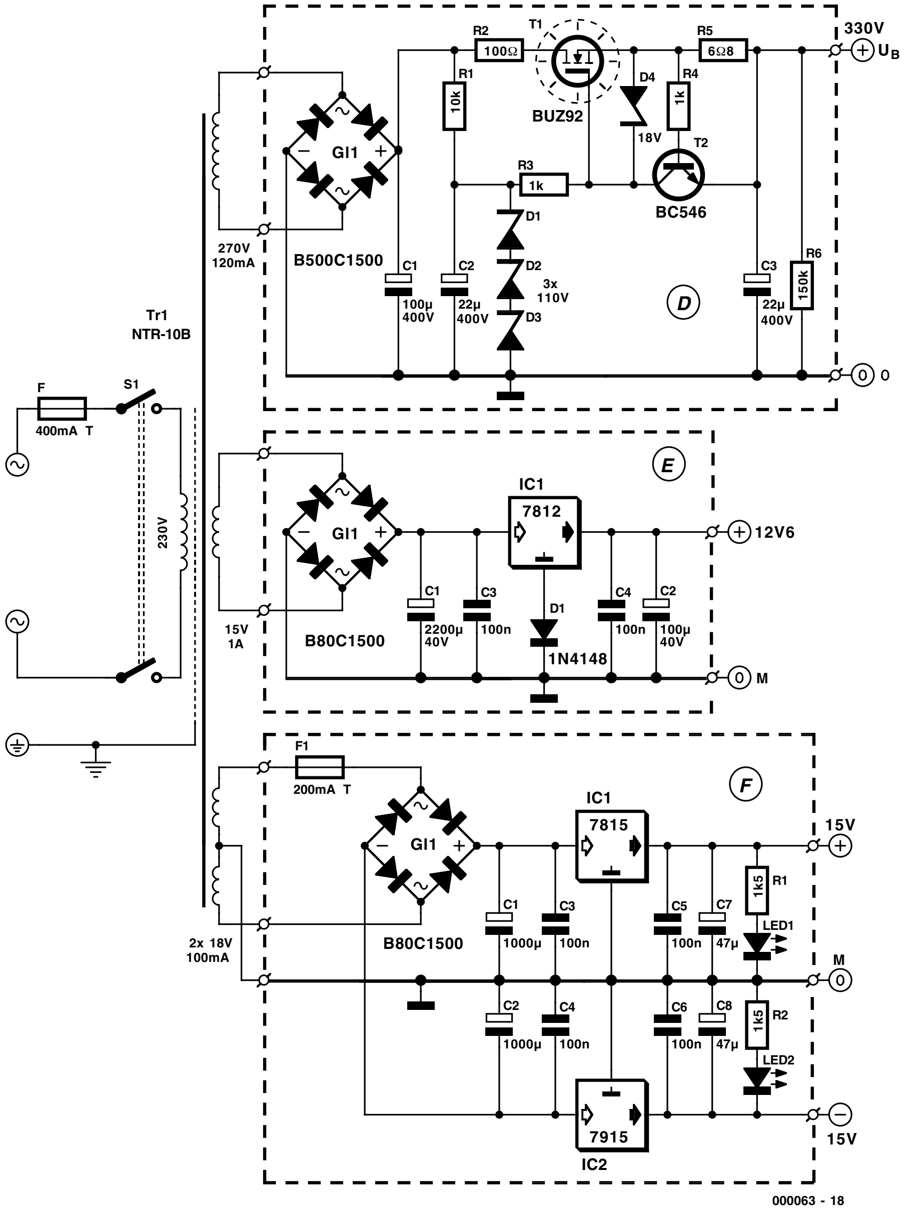

Figure 8. The power supply is a combination of a high voltage supply, a low voltage supply and an optional third supply.

pled and filtered for V1a by R8 and C2. Resistor R7 is a bleeder resistor that discharges the high-voltage electrolytic capacitors after the supply voltage has been switched off.

## Options

The input resistor R can be omitted, since the volume and balance adjustments also shunt static charges. However, if the amplifier module is used in some other application, any desired value can be used as necessary. The indicated connection between R9 and the anode of R1b should only be used if you want to operate the pentode in quasi-triode mode. In this case the combination of R15 and R16 is shorted out, and R9 is naturally redundant.

## Line or headphones

Using the ECL86 as a preamplifier valve has the additional advantage that the pentode section can deliver 4 watts of output power. This capability can be used to advantage by connecting a switched phone socket (K1) between the amplifier output and the line output. When a headphones plug is inserted into this socket, it automatically disables the line outputs. The pentode section of the ECL86, which can deliver a relatively large current, can easily drive headphones with an impedance greater than 300 Ω, even over a relatively long screened cable, without degradation of the sound quality. Normal screened cables are fully adequate for this purpose.

The portion of the circuit shown in **Figure 6** also includes two relays, which are driven by the protective circuitry. The two resistors bleed static charges to earth.

## Unconditional protection

The protective circuitry shown in **Figure 7** performs several tasks at the same time. Three conditions must be satisfied before the preamplifier is switched 'online'.

When the amplifier is first switched on, the outputs are initially shorted out via the relay outputs. The timer output of IC1 (pin 3) goes Low after approximately 100 s, at which time the valves should be properly warmed up and all charging processes completed. This delay prevents humming, burbling or other upsetting sounds from being generated by the speakers while the preamplifier is heating up. The output of inverter IC2b then sets input 2 of NAND gate IC2a High.

If a voltage is then present at pins AC1 and AC2, which are connected directly to the filament winding – diodes D1 and D3 monitor both half cycles of the AC waveform – then C1 is charged via R1 to 12 V (limited by D2). A High level is thus applied to input 1 of IC2a.

The DC components of the two output signals are monitored via connections DC1 and DC2. A DC voltage can for example be present if an output coupling capacitor breaks down. The AC components are shorted out by C2, which is discharged by R7. This combination also determines the time constant of the monitoring circuit. If a DC voltage higher than around 1.3 V is present, transistor T1 is driven via D5 and R4. This pulls input 8 of gate IC2a Low. A Schottky diode with a very low forward voltage drop is used to ensure that the monitor circuit will respond, even with very low values of the DC component. Transistor T1 is cut off only when no significant DC component is present, so that R9 can pull input 8 of gate IC2a high. Resistor R13 ensures that T1 is securely cut off in this situation. Diode D6 limits the maximum voltage applied to the base of T1, while R4 and C5 provide a short time delay, so that the circuit does not immediately respond to every tiny disturbance.

Only when all three of these conditions have been satisfied, so that all three inputs of the AND gate are High, will the protective circuit enable the output relays via inverter IC2c and the driver transistor T2.

When the mains transformer is switched off, the level at input 1 of the gate goes Low almost immediately. This causes the relays to be immediately disabled, so that no disturbance signals can be passed on to the following equipment while the capacitors in the preamplifier are discharging. The reset circuit consisting of R2, D4 and C1 also resets timer IC1 after a brief interruption of the mains power, so that the full delay time must expire each time. The delay time can be changed by modifying the values of R10 and C6. The time is equal to 1.1·RC. The protective circuitry is operated from the filament voltage power supply, with a voltage of 12.6 V.

## One transformer, three power supplies

A good power supply is essential for the proper operation of a preamplifier. Since the amplifier draws relatively little current, a cleanly filtered and stabilised power supply can be built economically using modern semiconductors. **Figure 8** shows the schematic diagram of the entire power supply circuit. This is also built using several separate circuit boards, which are indicated by dashed outlines.

The preamplifier needs a high voltage for the valves, as well as a low DC voltage for the filaments, the relays and the protective circuitry. These voltages, as well as some others, are provided by a single mains transformer (NTR-10B) that is protected by a 0.4-A slow-blow fuse on the primary side. This transformer is made using grain-oriented 0.35-mm steel laminations with especially low dispersion and losses, which are usually used for high-quality low-frequency coupling transformers. A very orderly winding technique and vacuum impregnation, which is not possible with toroidal transformers, provide long-term stability and corrosion resistance. The impregnating resin penetrates into the coils and permanently anchors each individual winding. Electrical safety is provided by a 4000-V breakdown test between the primary and secondary windings and a static screen that is connected to the protective earth lead. Obviously, you will not find this sort of high-end transformer in every electronics supermarket. It is only available from Experience Electronics, the author’s firm.

At the top of the schematic diagram, you can see the high voltage section. This circuit filters the hum voltage to a level that is below the intrinsic noise level. Resistor R1 and diodes D1 through D3 generate a good reference voltage with a value of around 330 V. Series regulator transistor T1 is a high-power V-FET (type BUZ92) in a TO-220 package. This allows the high voltage power supply to be constructed in a compact manner, using a small heat sink. The heat sink is mounted on the printed circuit board, with makes for short leads in the high voltage path. Resistors R4 and R5 and transistor T2 provide current limiting. With the indicated component values, this is set to around 90 mA. Resistor R6 discharges the electrolytic capacitors after the power is switched off. Zener diode D4 limits the gate voltage of T1, which must not exceed 20 V.

In order to avoid hum voltages, the filaments are powered by a DC supply. The frequently heard assertion that using a DC current for the filaments damages the valves is simply nonsense. All that is necessary is to bring the filaments to a particular temperature, so that the cathode can emit enough electrons. Whether this temperature is achieved using an AC current or a DC current does not matter. The ‘odd’ value of 6.3 V for the filament voltage, by the way, comes from the early days of valve technology, when the filaments were powered by four carbon-zinc batteries. Since fresh batteries have a terminal voltage of more than 1.5 V, a margin of 0.3 V was chosen to prevent the filaments of the (at that time) very expensive valves from burning out prematurely.

Each of the two ECL86 valve filaments draws 0.66 A at 6.3 V. To minimise the losses in the filament circuit, the two filaments are connected in series. A 12-V voltage regulator connected to earth via a 1N4148 forms a simple but good 12.6-V power supply for the filaments. The relays for the input selector are also powered by this supply. The aluminium mounting plate is used as a heat sink for the voltage regulator, which must be mounted using an insulator.

At the bottom of the circuit diagram you can see a third power supply that provides symmetrical ±15 V. This supply is not necessary, so it is optional. It can be used to power external devices, such as an equalisation preamplifier, from a non-earthed supply. If such a supply is already present in the preamplifier, you save the cost of a mains adapter and the associated cabling, and the external equipment can be switched on and off at the same time as the preamplifier. The aluminium mounting bracket is also used as a heat sink for this supply, which must be isolated. The supply voltage has additional protection in the form of two fuses in the transformer leads.

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*The second part of this article will include the printed circuit board and component layouts, the components list, precise construction information and, of course, performance data.*